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Ammonia and Nitrous Oxide Emissions from a Commercial Broiler House

D. M. Miles,* P. A. Moore, Jr., R. T. Burns, and J. P. Brooks

Complex variation in gas emissions from animal facilities has been shown in recent research reports. Uncertainties in these emission estimates are driving research activities concerning different animal species across the globe. Greenhouse gas (N_2O and CO_2) and NH_3 concentrations were measured in a modern, tunnel-ventilated, commercial broiler house in Mississippi during five flocks (spanning approximately 1 yr). These were flocks 9 through 13 on reused pine shavings litter, representing litter reuse beyond 2 yr. Gas concentrations obtained from a photoacoustic multigas analyzer were coupled with ventilation measurements of air flow through the house to develop NH_3 and N_2O emission rates. Ammonia emission during a flock (43 d) averaged approximately 14.8 ± 9.8 kg d^{-1} in the commercial house (equivalent to 23.5 g bird marketed^{-1} or 0.54 g bird^{-1} d^{-1}). Nitrous oxide emission averaged 2.3 ± 1.7 kg d^{-1} in the house (equivalent to 3.64 g bird marketed^{-1} or 0.085 g bird^{-1} d^{-1}). Emission rates increased with time from Day 1 to Day 43 and reached average values on Day 23 and 24 for NH_3 and N_2O. Even with extended litter reuse, estimates of NH_3 emissions from the broiler house agree well with recently published research that reused litter in eight or fewer flocks. This is important information for farmers who may not be able to afford to replace the litter with fresh bedding material annually.

The largest uncertainties in national gas emission inventories for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) are associated with agriculture, forestry, and other land uses primarily because of elevated uncertainty in emission factors (NRC, 2010). Specifically, more research is need on the biogeochemical cycles of these gases relative to human activities and for emissions from natural ecosystems to improve emission factors. In the latest national inventory report by the USEPA, agriculture is recognized as contributing 8% of all greenhouse gas (GHG) emissions in the United States (USEPA, 2013a). Sources of GHG emissions can be divided into five economic sectors: industry, transportation, electricity, agriculture, and commercial/residential. As with all sectors, large-scale producers in animal agriculture have been challenged to reduce their environmental footprint (NRC, 2003). This is not to say that emissions are confined to large producers; rather, these producers are the first to receive environmental scrutiny.

Generation of CH_4 and N_2O is cause for concern because of their contribution to the greenhouse effect and degradation of the ozone layer (Tamminga, 1992). The global warming potential of CH_4 is 25 times that of CO_2, whereas the same potential for N_2O is 298 times that of CO_2 (100 yr time horizon) (Forster et al., 2007). Regardless of being a GHG, CO_2 produced via animal respiration is not considered a contributing factor because it is produced from renewable sources as opposed to fossil fuels (Tamminga, 1992). It is generally not included in emission estimates because CO_2 from feed consumed comes from and is returned to the atmosphere (Verge et al., 2009). Relative to broiler production, Calvet et al. (2011) found that broiler litter accounted for 20% of the total CO_2 produced from a broiler facility. Wathes et al. (1997) reported that broiler litter is not a significant source of N_2O, CH_4, or CO_2, but increased study of animal feeding operations necessitates that emission factors and models be able to mitigate all emissions so that reducing one does not increase others. To represent diverse broiler production styles and climates, more research is needed to improve the

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Abbreviations: GHG, greenhouse gas; MIL, mobile instrument laboratory; NAEMS, National Air Emissions Monitoring Study.

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science-based emission inventory for the poultry industry and regulatory agencies (Lin et al., 2012; NRC, 2003).

Although not a GHG, NH_3 has long been the gas of interest in the poultry industry because it is a known irritant that can have negative effects on bird health and performance (Anderson et al., 1964; Charles and Payne, 1966; Miles et al., 2004). In more recent years with the concentrated production of human food, the effect of NH_3 on the environment has become a concern. Ammonia can degrade water quality due to eutrophication (Schroder, 1985; Hutchinson and Viets; 1969; USEPA, 2013b), acidify soil (van Breemen et al., 1982; ApSimon et al., 1987; Groot Koerkamp, 1998), and contribute to formation of fine particulate matter as ammonium sulfate or ammonium nitrate (Barthelmie and Pryor, 1998; McCubbin et al., 2002).

Because the atmospheres of individual countries are not well mixed, which gives rise to complex variation in GHG abundance at the surface and in the atmospheric column (NRC, 2010), mitigation must be targeted at the emission source. The primary objective of the current study was to determine emission rates of NH_3 and N_2O from a modern commercial broiler house in a humid, subtropical climate in the southeastern United States (Mississippi) on reused litter and to compare these rates with those used in national inventories. A secondary objective was to report the gas concentrations of NH_3, N_2O, and CO_2 to show the variability among consecutive flocks. The novelty of the work resides in that the litter was reused for longer than 1 yr. Whereas European houses are cleaned out after each flock and usually once per year in the United States (Moore et al., 2011), this work was conducted on litter that had been reused for approximately 2 yr at the beginning of the study.

Materials and Methods

Broiler House Description and Flock Management

This research was conducted on a commercial broiler farm in east-central Mississippi in 2007. One tunnel-ventilated house, measuring 13 m by 152 m, was selected from a group of four houses on the farm; the (north-to-south oriented) houses were built in 2005 (Fig. 1). The research house was between the eastern-most house and the other interior house. The house had solid sidewalls with an insulated drop ceiling; box inlets (0.15 m by 1.52 m) in the upper sidewalls that were 6.1 m apart; two automatic feeder lines spanning the length of the house; four automatic nipple waterer lines, one on each side of the feeder lines; infrared propane heaters (brooders) hanging from the center of the ceiling also spanning the length of the house; one 0.91-m-diameter fan and 10 1.22-m-diameter tunnel fans in the nonbrood half of the house (south end); evaporative cooling pads in the sidewalls of the brood half of the house (north end); and two 0.91-m-diameter fans in the brood half (one near the middle and one in the end) for the purpose of minimum ventilation. These minimum ventilation fans were not used during data collection.

Pine wood shavings were the original bedding material placed on the floor of the house; the litter had been reused during flocks 9 through 13 for this research. Decaking (i.e., removing the cake or upper compacted layer of litter) was performed between flocks (Sistani et al., 2003). Decaking was accomplished by pulling a decaking machine (Poultry Housekeeper; Lewis Brothers Manufacturing) over the house floor. During each growout,

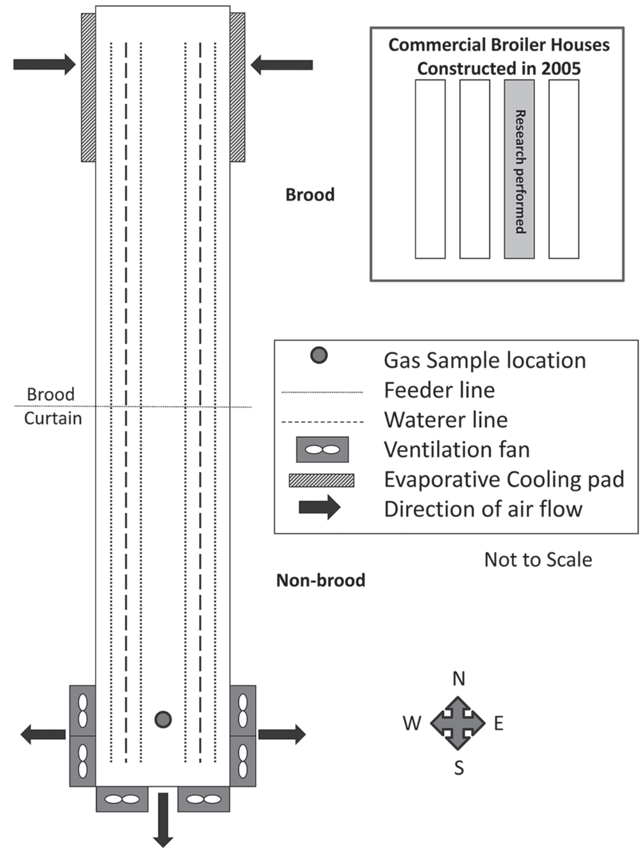

Fig. 1. Plan view of commercial broiler house.

migration fences divided the house lengthwise into quarters. Each flock operated in all in/all out mode, placing an average of 27,860 birds on Day 1. Birds were grown to approximately 2.27 kg, with an average growout period of 43 d. The mortality rate was approximately 2.6%, resulting in an average of 27,136 birds marketed flock^{-1}. The flock dates were: flock 9, 25 January to 7 March (42 d); flock 10, 26 March to 8 May (43 d); flock 11, 29 May to 10 July (43 d); flock 12, 30 July to 11 September (44 d); and flock 13, 2 October to 13 November (43 d).

After each flock (before decaking), litter samples were collected from the upper 5 cm and analyzed for moisture content, pH, and total N. Samples were oven dried at 65°C for 48 h to determine the moisture content by loss of weight; a deionized H_2O:litter ratio of 5:1 was used to determine pH. Total N was determined via combustion of a 0.2-g sample (Thermo Finnigan model Flash EA1112Series, Elantech, Inc.). Because litter samples for flock 13 were accidentally discarded before analysis, no litter characteristic data exist for this flock.

Gas Emission Monitoring System

Primary instrumentation for developing broiler emissions was housed in a Mobile Instrument Laboratory (MIL) adjacent to the west side of the house near the tunnel fans. The MIL was a 1.83 m by 3.05 m climate-controlled trailer to protect the gas analyzer and ventilation monitoring equipment. Gas concentrations in the house were measured using a photoacoustic multigas analyzer (Innova 1412, California Analytical) configured to analyze NH_3, N_2O, CO_2, and water vapor. An air sampling line (0.9525 cm o.d. × 0.635 cm i.d. fluorinated ethylene propylene tubing; Saint-Gobain Performance Plastics) ran underground from the MIL to a junction box in the house sidewall; this portion of the line was insulated and wrapped with temperature-controlled heat tape to prevent condensation within the sample tubing. The remainder of the gas sampling line ran along the ceiling from the junction box to the middle of the house tunnel fan area, approximately 3 m from the end wall, suspended to mid-fan height. This single location represented the exhaust air sampling port for the broiler house. The port was made from 250-mL bottle with a plastic screw cap (1.27-cm holes drilled through the sides for air intake). The bottle cap was drilled to fit the sample tubing through it and to extend the tubing approximately 7.6 cm into the bottle. The line inlet was covered with polyester batting filter material to prevent the possible intake of dust and feathers. The self-contained pump of the multigas analyzer drew the gas sample through the tubing from the port. This configuration was deemed satisfactory after introducing calibration gases to the port. Also, after each flock, the multigas analyzer was exposed to calibration gases (0 [normal air], 50, and 100 ppm_v NH_3 balanced in air; 24.9 ppm_v N_2O balanced in N; and 4513 ppm_v CO_2 balanced in N) to ensure the instrument remained calibrated. Gas samples were collected and analyzed every 10 min throughout each flock.

Emission rates can only be determined by coupling them with the amount of ventilation through the facility at any given time. The air flow through the house was characterized by in situ calibration of each fan using a Fan Assessment Numeration System (Gates et al., 2004) to develop curves under various static pressures within the house. Although manufacturers report a characteristic value for air flow for a given fan size, this can vary due to many factors, such as age of the fan, belt tightness, and other maintenance factors (e.g., dust load) but especially due to the placement of the fan along the side or end wall of the broiler house. The relative on/off time of each fan was determined by the activity of cup anemometers (model 03101–5 wind sentry anemometer, R.M. Young) situated in front of each fan. The anemometer speed was recorded each minute using a datalogger (CR10X, Campbell Scientific).

Emission Rate Development

A Matlab program was written to combine the gas concentration measurements with the air flow through the house (Matlab, 2013). Because continuous monitoring of the house static pressure was not possible, a nominal value was chosen based on observation of the house management. The nominal value for each fan was written into the Matlab code; it is understood that this can induce up to a 10% error by using the assumed fan flow rate. Based on the anemometer speed and in-house observation, the on/off status of the fan was designated “On” if the speed was more than 3.5 m s^{-1}. Anemometers in front of the sidewall fans could falsely show anemometer activity (below the 3.5 m s^{-1} threshold) when the end wall fans were running. Using the threshold ensured the accuracy of the fan status.

The program used a modified version of the equation given by Burns et al. (2008), in this case calculating gaseous emission rate from the house in g min^{-1} instead of g h^{-1}. Background gas concentrations (measured at the northwest corner of the house, outside the evaporative cooling pads) were low compared with in-house concentrations (measured before flock 9 only: <2 ppm_v NH_3 and <0.1 ppm_v N_2O). These were considered negligible and were not subtracted from the in-house gas concentrations before determining emissions. To calculate the emission rate, the sum of the ventilation rate (Q_f, m^3 min^{-1}) is multiplied by the gas concentration (G_f, in ppm by volume [ppm_v]) as well as the appropriate conversion factors as shown in the following equation:

$$\mathrm{ER_G} = \sum_{f=1}^{11} Q_f\left(G_f\right) \times 10^{-6} \times \frac{w_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}}$$

where ER_G is the gaseous emission rate for the broiler house (g min^{-1}); Q_f is the ventilation rate of the exhaust fans (m^3 min^{-1}); G_f is the gaseous concentration inside the house, near the fans (ppm_v); w_m is the molar weight of the gas (g mol^{-1}); V_m is the molar volume of gas at standard temperature and pressure (0.022414 m^3 mol^{-1}); T_{std} is the standard temperature (0°C or 273.15 K); T_a is the absolute house temperature (°C + 273.15 K); P_a is the atmospheric barometric pressure at the site (atm); and P_{std} is the standard pressure (1 atm). For each day, the 10-min average emission rates (g min^{-1}) were used to determine the average daily emission rates (kg d^{-1}) plotted in Fig. 2 and 3 for NH_3 and N_2O, respectively.

Statistical analyses of the emission rates for each gas were performed using SAS procedures (SAS Institute, 2003). Specifically, PROC GLM was used to determine the mean emission rate for each flock, with flock as the single classification variable. This analysis assumes that mean emission rates will not be correlated across time (with advancing flocks), a valid assumption based on how seasonal changes affect house management, which is dictated by bird rearing. Significant

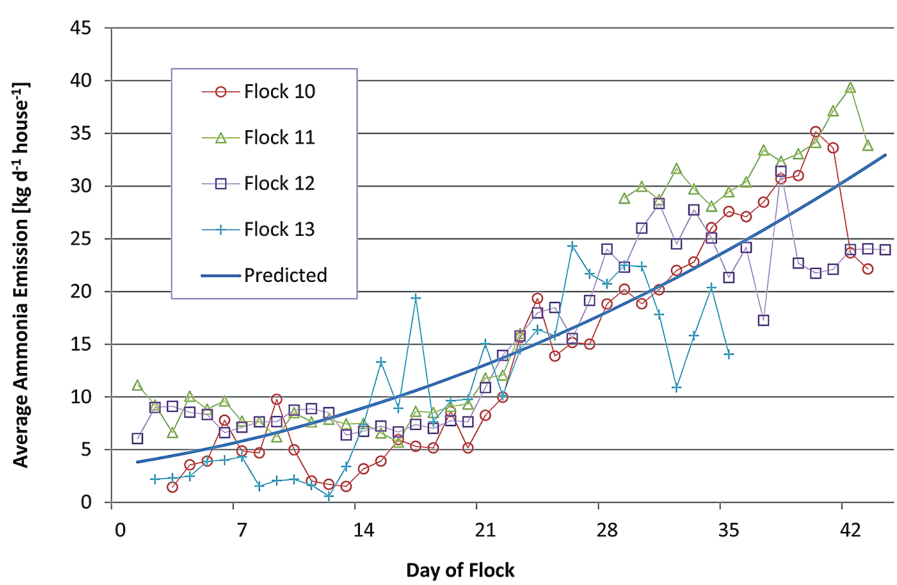

Fig. 2. Average daily NH_3 emissions from a commercial broiler house during flocks 10 through 13 on reused pine shavings litter ($LSD_{0.05}$ = 4.29). The predicted overall average of the data is described by: NH_3 (kg d^{-1}) = 0.0094 × (day of flock)^2 + 0.2542 × day of flock + 3.5663 (R^2 = 0.8993).

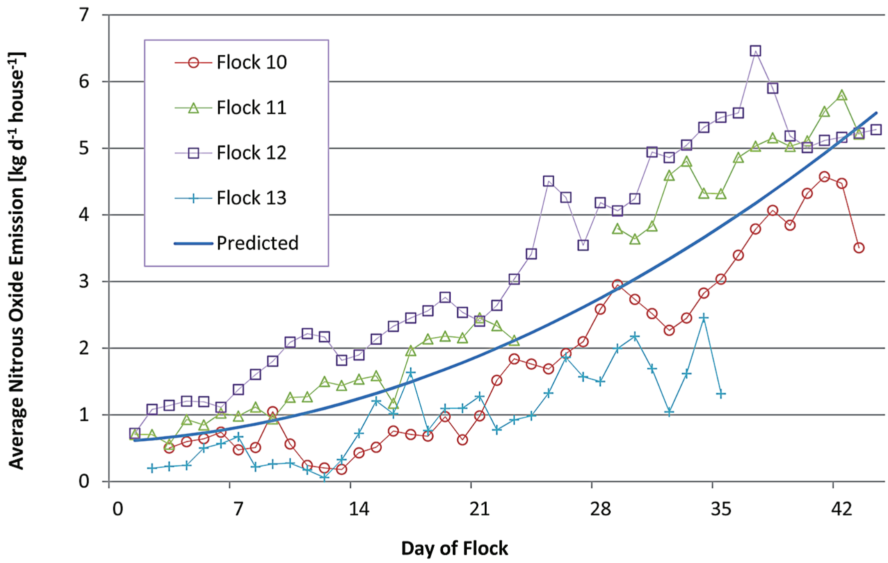

Fig. 3. Average daily N_2O emissions from a commercial broiler house during flocks 10 through 13 on reused pine shavings litter ($LSD_{0.05} = 0.65$). The predicted overall average of the data is described by: N_2O (kg d^{-1}) = 0.0022 × (day of flock)^2 + 0.0153 × day of flock + 0.5968 ($R^2 = 0.9729$).

differences were declared at the $P < 0.05$ level, determined by Duncan's new multiple-range test.

Results and Discussion

Table 1 shows the average daily NH_3, N_2O, and CO_2 concentrations for each flock along with average in-house temperature, dates and duration of each growout, number of birds placed, average ventilation rates, overall emission rates, and litter properties (i.e., total N, pH, and moisture content). The highest average concentration of NH_3 (39.9 ± 16.7 ppm_v) occurred in flock 9, which had the lowest in-house temperature (20.7 ± 3.3°C, late January to early March). The lowest NH_3 average concentration (6.3 ± 3.6 ppm_v) occurred in flock 12, the prime summer growout from late July to mid-September having an average in-house temperature of 28.9 ± 3.0°C. Knixatova et al. (2010) observed the lowest concentrations of NH_3 during summer conditions where ventilation rates were higher. The greatest average concentrations of N_2O (1.41 ± 0.40 ppm_v) and CO_2 (2342 ± 757 ppm_v) also occurred in flock 9. Lower ventilation during the winter growout is likely the cause of the increased gas concentrations in the house. Flock 9 was the first flock monitored using the MIL. Wiring issues (primarily loose connections at the anemometer mounts) precluded the characterization of the air flow through the house during this flock and the subsequent development of gas emission rates. The lowest average concentrations of N_2O (0.47 ± 0.10 ppm_v) and CO_2 (707 ± 227 ppm_v) were evident in flock 12. Flock 12 had the highest average ventilation rate among all the flocks (Table 1). During the final 2 wk of the growout, 10 1.22-m fans created maximum air flow (5364 m^3 min^{-1}) for much of the fifth week of the flock, and nine 1.22-m fans (4814 m^3 min^{-1}) ran continuously in the sixth week (data not shown). For comparison, maximum ventilation rates measured by Redwine et al. (2002) were 5340 m^3 min^{-1} during summer conditions in commercial broiler houses in Texas.

Litter moisture content varied widely from flock to flock, beginning with 31.7% moisture in flock 9. Between flocks 9 and 10, a large amount of cake was removed from the house, and the litter was top dressed with new pine shavings, which should account for the drastic drop in litter moisture to 14.6% at the end of flock 10. From this time, litter moisture increased in flocks 11 and 12 to 24.3 and 36.2%, respectively. Litter pH did

Table 1. Commercial broiler house average per flock ventilation rates; NH_3 and N_2O emission rates; aerial NH_3, N_2O, and CO_2 concentrations; and litter properties during flocks 9 through 13 on reused pine shavings litter.

	Flock 9 (25 Jan.–7 Mar., 42 d)	Flock 10 (26 Mar.–8 May, 43 d)	Flock 11 (29 May–10 July, 43 d)	Flock 12 (30 July–11 Sept., 44 d)	Flock 13 (2 Oct.–13 Nov., 43 d)
Birds placed	28,000	28,000	28,000	27,000	28,300
In-house temp., °C	20.7 ± 3.3†	25.8 ± 2.6	28.7 ± 2.8	28.9 ± 3.0	26.3 ± 2.8
Ventilation rate, m^3 min^{-1}	nd‡	1290 ± 1490	2180 ± 1670§	3050 ± 1760	700 ± 900
Emission rate, kg d^{-1} $house^{-1}$					
NH_3 (LSD = 4.29)	nd	14.4	18§	15.4	10.9§
N_2O (LSD = 0.65)	nd	1.84	2.74§	3.34	0.99§
Aerial gas concentrations, ppm_v					
N_H3	39.9 ± 16.7	16.7 ± 7.3	12.0 ± 9.2	6.3 ± 3.6	22.3 ± 11.5§
N_2O	1.41 ± 0.40	0.81 ± 0.29	0.60 ± 0.21	0.47 ± 0.10	0.75 ± 0.25§
CO_2	2342 ± 757	1477 ± 656	893 ± 321	707 ± 227	1559 ± 726§
Litter properties					
N, g kg^{-1}	42.6	34.9	34.8	40.9	nd
pH	8.2	8	8.2	8.3	nd
Moisture, %	42.1	14.6	24.3	36.2	nd

† Numerals following "±" represent the SD.

‡ No data.

§ Incomplete data sets: flock 11 had no ventilation data for week 4; flock 13 had no gas concentration data for week 6.

not vary with the same magnitude as litter moisture, averaging 8.2 over all flocks. Litter total N ranged from 32.0 g N kg^{-1} (flock 9) to 40.9 g N kg^{-1} (flock 12). It is well known that litter moisture affects NH_3 emission (Carr et al., 1990; Miles et al., 2011), but the emission rate data (discussed below) suggest that the dynamic nature of the broiler house management, specifically the ventilation rate, is a gross controlling factor of broiler house emissions.

Daily average NH_3 and N_2O emissions from the commercial broiler house are shown in Fig. 2 and 3, respectively. Each day on these graphs represents the average of 144 gas concentration measurements and 1440 ventilation measurements. During the four flocks for which emission rates were developed, two data files were lost: (i) ventilation data for week 4 of flock 11 and (ii) gas concentrations for the final week of flock 13. The missing data were likely responsible for causing a decrease in the overall mean emission rate for flock 13 (Table 1). Previous work has shown (Moore et al., 2011) that emission rates increase with bird age. The missing 2 wk of data from flocks 11 and 13 comprise 8.3% of the 24 wk of emission data for all flocks. Thus, the overall emission rate was derived from all flocks, but the individual emission rates from flocks 11 and 13 are not discussed here.

Daily average NH_3 emissions did not appear different for flocks 10 and 12 (Table 1). By fitting the average daily emission rate from all flocks, an equation to predict NH_3 emissions was determined to be NH_3 (kg d^{-1}) = 0.0094 × (day of flock)^2 + 0.2542 × day of flock + 3.5663 (R^2 = 0.8993). The predicted equation is plotted on Fig. 2. For this house, the overall average NH_3 emission rate was 14.8 ± 9.8 kg d^{-1}, with a minimum rate of 0.6 kg d^{-1} and a maximum of 39.4 kg d^{-1}. The overall average NH_3 emission rate was equivalent to 23.5 g bird marketed^{-1} or 0.54 g bird^{-1} d^{-1}. Using the predicted emission equation, the average value would occur on Day 23 of the flock.

The National Air Emissions Monitoring Study (NAEMS) recently reported air emissions from broiler houses in California (Lin et al., 2012). Ammonia emission rates from the two houses in the NAEMS study (21,000 birds placed; growout, 46 d) were 0.503 ± 0.436 g bird^{-1} d^{-1}. The average NH_3 emissions in the current study agree well with those found by Lin et al. (2012), with Moore et al. (2011) from broiler houses in Arkansas, and with other works mentioned in Table 2. Most of the compared works used litter for 1 yr or less. For the average flock of 26,300 birds, NH_3 emissions were approximately 15.2 kg d^{-1} house^{-1} or 28.3 g bird marketed^{-1} (Moore et al., 2011). Because of a longer growout period in the Moore et al. (2011) study (42–57 d), it is expected that these values are slightly higher than those found in the current study. Another study by Redwine et al. (2002) had a 49-d growout with 27,500 birds placed and reported a range of NH_3 emissions from four commercial broiler houses in Texas at 0.91 to 50.5 kg d^{-1} house^{-1}, which agrees well with the minimum and maximum average NH_3 emission reported here (Fig. 2). Casey et al. (2004) reported a range of 0.14 to 1.92 g bird^{-1} d^{-1} for litter aged 2 to 5 flocks for houses in Kentucky. For a 43-d flock, the Casey et al. (2004) range is equivalent to 6.02 to 82.6 g bird^{-1}, or, for the same number of birds marketed in this study (27,136), it is equivalent to a range of 3.8 to 52.1 kg d^{-1} house^{-1}.

The National Emission Inventory-Ammonia Emissions from Animal Husbandry Operations, Draft Report (USEPA, 2004) uses 0.22 lb yr^{-1} head^{-1} for broiler emissions. However, it is unclear if "yr^{-1} head^{-1}" means one bird in a flock or if the conversion requires 5.5 flocks yr^{-1}. In the first case, using one bird in a flock and comparing the NH_3 emission rate found in this study, the use of 0.22 lb yr^{-1} head^{-1} (USEPA, 2004) is approximately four times higher than on-farm measurements of average broiler NH_3 emissions. To convert the inventory quantity (0.22 lb yr^{-1} head^{-1}), we use head = bird, 1 lb = 453.59 g, and during the year a broiler is present in only one flock. Thus, converting 0.22 lb flock^{-1} bird^{-1} equates to 2.32 g bird^{-1} d^{-1} for a 43-d flock or 63 kg d^{-1} for marketing 27,136 birds in that flock. These quantities are also in excess compared with the reports by Casey et al. (2004), Redwine et al. (2002), Lin et al. (2012), and Moore et al. (2011). In the second case, using 5.5 flocks yr^{-1}, the inventory would underestimate NH_3 emission rates in this study by approximately 28%.

Daily average N_2O emissions were greater in flock 12 than in flock 10 (Table 1). Fitting the average daily emission rate from all flocks resulted in the equation N_2O (kg d^{-1}) = 0.0022 × (day of flock)^2 + 0.0153 × day of flock + 0.5968 (R^2 = 0.9729). The predicted equation is plotted in Fig. 3. The overall average N_2O emission rate for the four flocks was 2.3 ± 1.7 kg d^{-1}, with a minimum rate of 0.1 kg d^{-1} and a maximum of 6.5 kg d^{-1}. The overall average was 3.64 g bird marketed^{-1} or 0.085 g bird^{-1} d^{-1}. Using the prediction, the average N_2O emission occurred on Day 24 of the flock.

Burns et al. (2008) found that N_2O emissions varied from 0.1 to 3.4 kg d^{-1} in a commercial broiler house (13 m by 156 m) in Kentucky, with an average emission from six flocks of 0.68 kg d^{-1}. No other reports of continuous aerial measurements of N_2O in U.S. broiler houses were found in the literature. The lower emission rate found by Burns et al. (2008) could be attributed to many factors, such as differences in house management, variable length of litter reuse, feed inputs, poultry company, and climate in Kentucky vs. Mississippi, but it is most likely due to the assumed air flow rates for each fan in the current study, whereas Burns et al. (2008) used flow rate coupled with static

Table 2. Commercial broiler house NH_3 emission rates in recently published literature.

Reference	NH_3			Birds placed	Growout period	Litter age
	kg d^{-1} house^{-1}	g bird^{-1} d^{-1}	g bird^{-1}		d	
This work	14.8	0.54	23.5	27,900	43	9–13 flocks
Lin et al., 2012 (NAEMS)		0.503		21,000	46	≤3 flocks
Moore et al., 2011	15.2		28.3	25,000–30,700	42–57	1–5 flocks
Casey et al., 2004		0.14–1.92		20,000–25,000	55–64	2–5 flocks
Redwine et al., 2002	0.91–50.5			27,500	49	1–4 flocks, center of house
						1–8 flocks, ends of house

pressure measured every second. Measurement error associated with ventilation rate is a primary contributor to emission rate uncertainty (Gates et al., 2009).

In conclusion, the extent of litter reuse (during Year 3) did not grossly elevate the emission rates of NH_3 and N_2O beyond other published works where litter had been used during a single year or less. This is important information for farmers who may not be able to afford to replace the litter with fresh bedding material annually. More studies are needed to develop a representative estimation of N_2O emissions from U.S. commercial broiler facilities. Uncertainty in the units for the factor used in the national emission inventory of NH_3 emissions from broilers (USEPA, 2004) could indicate that U.S. poultry houses emit less NH_3 than previously estimated. Inventory units need to be clarified for broilers, and estimates should be updated to include published emission factors determined in U.S. broiler houses during the previous decade.

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